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Diffusive Separation in the Upper Atmosphere

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Reports have been given [Nier et al. 1964a and b] on an Aerobee flight launched at 0730 MST, June 6, 1963, at the White Sands, New Mexico missile range in which a magnetic mass spectrometer measured the principal neutral constituents of the atmosphere in the altitude region 100 - 200 km.

In a detailed analysis of the data, Hedin et al. [1964] fitted the data to a theoretical expression which took account of rocket trajectory, source orientation and source geometry. Because the rocket speed was comparable with average molecular speeds, the particle densities measured in the ion source of the mass spectrometer varied drastically as the rocket rotated, and the ion source alternately looked "forward" and "backward". The analysis not only corrected the measured densities for the modulation effect but also obtained from it as a by-product, the kinetic temperature of the various neutral constituents throughout the altitude range studied. Curve A in Figure 3 of their paper gives as a function of altitude the temperature so found and Figure 5 the number densities of N_2, O_2, O and Ar. An examination of these latter curves shows that the heavier the particle, the more rapid the decrease of density with altitude, in qualitative agreement with expectations if the particles

are in diffusive equilibrium.

On the basis of theoretical considerations, Nicolet and Mange [1954] concluded that the oxygen in the upper atmosphere should be in diffusive rather than photochemical equilibrium. Meadows and Townsend [1960], Meadows-Read and Smith [1964], Polshunkov [1963] and Schaefer and Nichols [1964] have shown that the Ar/N_2 ratio falls off with altitude, as is to be expected if the constituents are in diffusive equilibrium. To date there has been no comparison between experiment and theory to see if each of the principal constituents, N_2, O_2, O and Ar quantitatively satisfies the diffusive equilibrium condition at sufficiently high altitudes. The present data lends itself to such a study since there was a simultaneous measurement of temperature. Above 120 km the temperature variation with altitude agrees well with that measured in other experiments.

If one starts with the familiar equations $dp/dz = -nmg$, relating pressure, number density and mass of particle to altitude in an atmosphere in hydrostatic equilibrium, and $p = nkT$, relating pressure, number density and temperature, one obtains the well known differential equation

$$dn/dz = -n/T\left[mg/k + dT/dz\right] \tag{1}$$

which when integrated from some reference level, z_o, where the number density is n_o and the temperature T_o yields

$$n = n_o T_o/T \exp\left(-m/k \int_{z_o}^{z} (g/T)dz'\right) \tag{2}$$

This expression was applied to each of the constituents N_2, O_2, O, and Ar, using the temperature variation with altitude found in the experiment. In performing the integration, g varied according to an inverse square law. One hundred and fifty km was arbitrarily chosen as a reference level in performing the integration. This altitude was chosen as it was expected to be in the diffusive equilibrium region. The expression was normalized so that the theoretical and experimentally determined values agreed at this level. Figure 1 shows the result of the comparison. Two curves are shown for N_2, one based on the measurement of the 28 peak in the mass spectrometer, the other based on the measurement of the 14 peak, on the assumption that all of the 14 peak observed in the mass spectrometer is due to the dissociation of N_2 in the ion source and hence is proportional to the amount of N_2 observed.

The agreement between calculation and experiment is gratifying considering the difficulties in making the measurement, and one concludes that in the 120 - ~~205~~ 225 km range studied, the N_2, O_2, O and Ar approach very close to being in diffusive equilibrium. For the present it would seem safest to attribute the slight discrepancies which exist to errors in mass spectrometer calibration or measurement. Nevertheless there are a few effects exhibited here which should be looked for in future experiments. For example, the measured O_2 attenuation with altitude appears slightly steeper than predicted, suggesting that this constituent may not be in complete diffusive equilibrium. Another effect is that the N_2 concentration computed from the measurement of the 14 peak is slightly larger than that found from the 28 peak.

Moreover the difference varies with altitude with a slope very nearly the same as that of O. Thus it could possibly be attributed to a concentration of atomic nitrogen of the order of one percent. Clearly further experiments are required before this explanation can be accepted.

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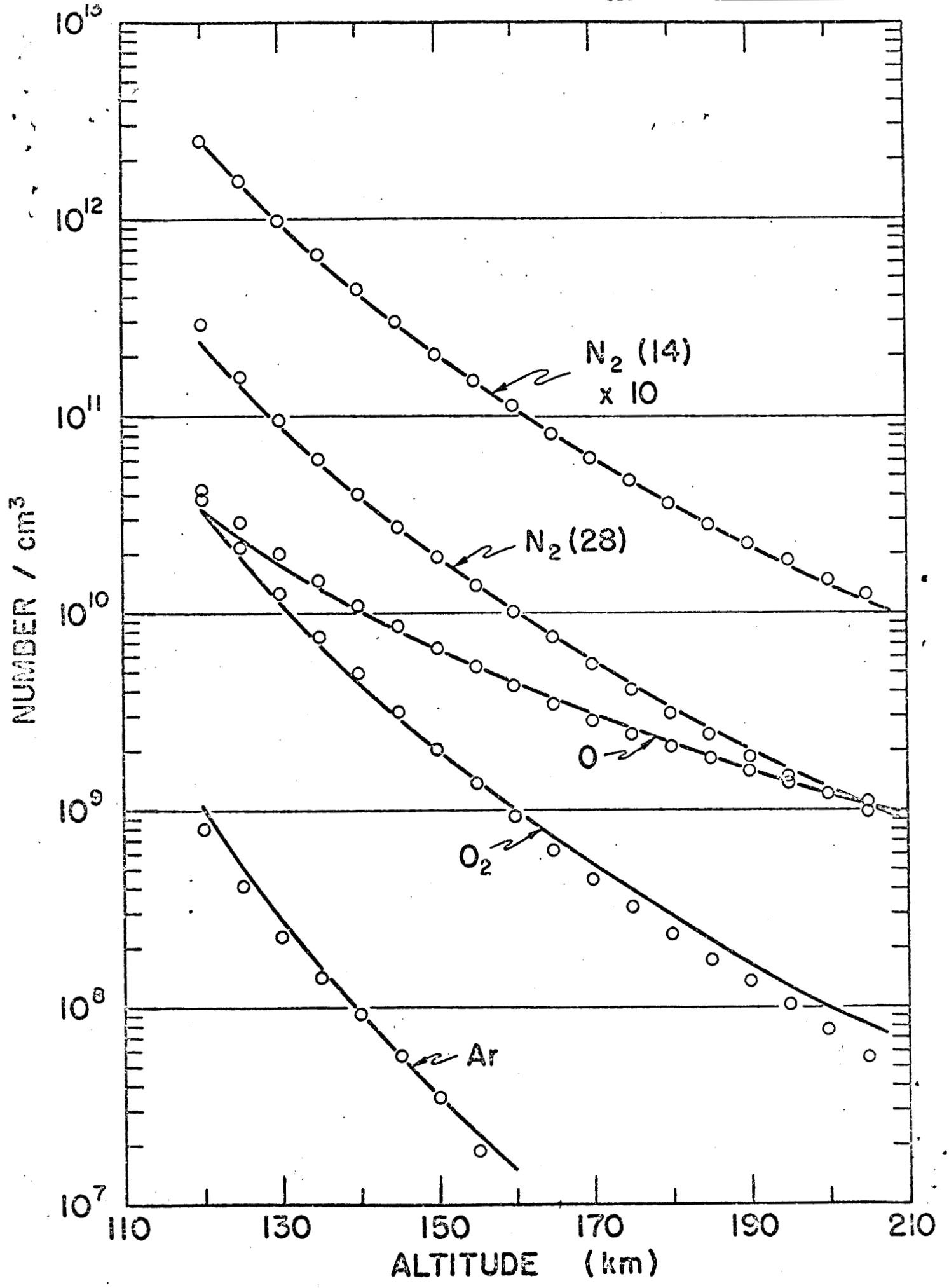
Caption for Figure

Fig. 1 Number densities of N_2, O_2, O and Ar versus altitude. Circled points are values taken from Hedin et al. [1964]. Solid curves were computed from Eq. (2) with values normalized at 150 km.


NUMBER / cm³
ALTITUDE (km)
N₂ (14)
x 10
N₂ (28)
O
O₂
Ar

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